National Aeronautics and
Space Administration
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Critical Viscosity of Xenon-2 (CVX–2) on STS–107

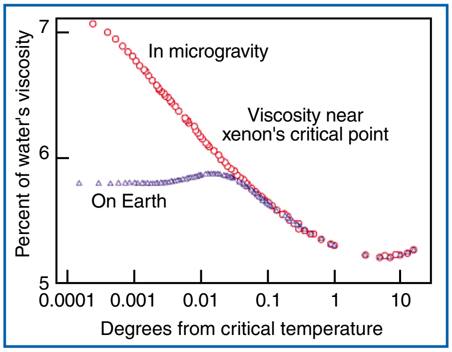
Stirring Up an Elastic Fluid

Whipped cream stays in place even when turned upside down. Yet it readily flows through the nozzle of a spray can to reach the dessert plate. This demonstrates the poorly understood shear thinning phenomenon that is important to many industrial and physical processes. Modern society uses paints, film emulsions, and other complex solutions that are highly viscous under normal conditions but become thin and flow easily under shear forces.

A simple fluid, such as water, does not exhibit shear thinning under normal conditions. Very close to the liquid-vapor critical point, where the distinction between liquid and vapor disappears, the fluid becomes more complex and is predicted to display shear thinning. Behavior in a "critical" state can illuminate how a wider range of materials behave under "normal" conditions. In turn, this may help engineers understand and refine a number of manufacturing processes.

Whipped cream is a familiar material that exhibits the shear-thinning effect seen in a range of industrial applications. It is thick enough to stand on its own atop a piece of pie, yet flows readily when pushed through a tube.

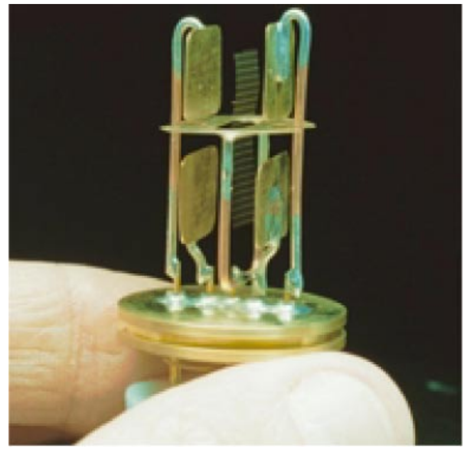
The Critical Viscosity of Xenon-2 Experiment (CVX–2) will measure the viscous behavior of xenon, a heavy inert gas used in flash lamps and ion rocket engines, at its critical point. Although it does not easily combine with other chemicals, its viscosity at the critical point can be used as a model for a range of chemicals.



Because xenon near the critical point compresses under its own weight, experiments on Earth are limited as they get closer (toward the left) to the critical point. CVX in the microgravity of space moved into unmeasured territory that scientists had not been able to reach.

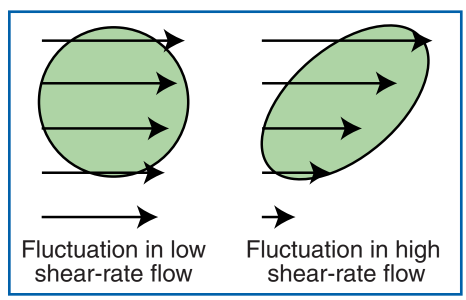
Viscosity originates from the interactions of individual molecules. It is so complicated that, except for the simplest gas, it cannot be calculated accurately from theory. Tests with critical fluids can provide key data, but are limited on Earth because critical fluids are highly compressed by gravity. CVX–2 employs a tiny metal screen vibrating between two electrodes in a bath of critical xenon. The vibrations and how they dampen are used to measure viscosity.

The Critical Viscosity of Xenon (CVX) flew on the STS–85 mission, where it revealed that, close to the critical point, the xenon is partly elastic: it can "stretch" as well as flow. For STS–107, the hardware has been enhanced to determine if critical xenon is a shear-thinning fluid.



Resembling a tiny bit of window screen, the oscillator at the heart of CVX–2 will vibrate between two pairs of paddle-like electrodes. The slight bend in the shape of the mesh has no effect on the data.

On CVX, the screen oscillated at less than 13 cycles per second (13 Hz) through a distance of less than 0.01 mm, less than the thickness of a hair, to avoid disrupting the density fluctuations in the xenon. On CVX–2, the screen vibrates at up to 25 Hz and amplitudes of 0.3 mm in a deliberate attempt to disrupt the density fluctuations and cause shear thinning.



Shear thinning will cause a normally viscous fluid to deform and flow more readily under high shear conditions.

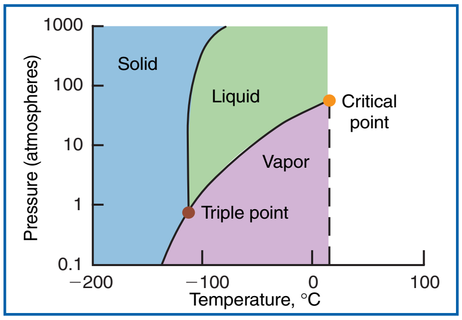
Applications

An understanding of shear thinning in a simple fluid such as xenon will help scientists understand shear thinning in more complex, industrially important fluids, such as

- Paints, emulsions, and foams
- Polymer melts
- Pharmaceutical, food, and cosmetic products

Science

Viscosity—the "thickness" of fluids—is determined by complex interactions between molecules. Except for low density helium, fluid viscosity cannot be predicted accurately by current theory. Progress is being made with experiments using simple fluids near their critical points, a combination of pressure and temperature at which a fluid is balanced between the states of liquid and gas. This balance causes the fluid to fluctuate spontaneously between liquid and gas at a microscopic scale.



Phase diagram of xenon. There is no distinction between liquid and vapor above the critical point.

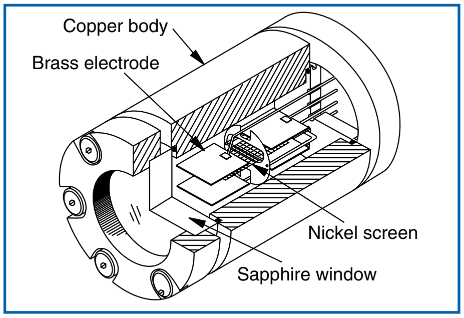
Experiments on Earth are highly limited. At 0.001 °C above the critical temperature, or Tc, xenon is 6000 times more compressible than air. Even a fluid layer as thin as a dime (1 mm) compresses under its own weight, thereby increasing the density at the bottom. Experiments in the microgravity of orbit eliminate density differences and allow extended experiments to achieve the precision that scientists need.

Shear thinning occurs in complex fluids, such as paints and blood, that become "thin" and easily flow under a shear stress such as stirring or pumping. CVX–2 will be the first experiment to examine the shear-thinning phenomenon in a simple fluid.

Hardware

The heart of CVX is a viscometer comprising a nickel screen that vibrates between two pairs of brass electrodes in a xenon bath near the critical point. The grid is 7 × 9 mm and weighs less than 1 mg. An electrode is positioned 4 mm to each side of the screen. An electrical charge applied by the electrodes will oscillate the screen. The electrodes then measure the screen's displacement and period, like a pendulum swinging in a liquid.

The sample cell (left) at the heart of CVX will sit inside a thermostat (right) providing three layers of insulation. The cell itself (below) comprises a copper body that conducts heat efficiently and smoothes out thermal variations that would destroy the xenon's uniformity.



Xenon is a heavy inert gas. The CVX–2 cell holds a small quantity of xenon near the critical temperature (Tc = 16.6 °C, or 62 °F) and critical density (1.1 times that of ordinary water). The resulting pressure is 58 atm, equivalent to a depth under water of 0.6 km.

Because the critical condition requires microdegree control, the sample cell is a copper cylinder, 62-mm long by 38-mm wide that conducts heat well and adds thermal inertia to ensure slow, even changes in temperature. The cell is enclosed in a three-layer thermostat to improve thermal control.

The complete CVX–2 system is contained in two Hitchhiker canisters mounted on the Multi-Purpose Equipment Support Structure (MPESS) in the shuttle payload bay as part of the FREESTAR payload. One canister holds the thermostat, batteries, and analog control electronics. The second canister holds the control electronics, data recorders, and communications system.

CVX–2 will start functioning after the Space Shuttle crew activates it on orbit. Normal operations are automated, but CVX–2 can be controlled from a payload control center at NASA's Goddard Space Flight Center. The experiment plan involves 4 "sweeps" through Tc. That is, the temperature will be gently moved up and down through Tc while the screen oscillates and data is continuously recorded.

Following activation, CVX–2 cools and stabilizes at Tc + 1 °C. Then it is slowly cooled to Tc − 0.02 °C during the next 3 days. CVX–2 will determine Tc to within 0.001 °C. These first results will be compared to those from CVX. Over the next 7 days, the temperature sweeps from Tc + 1 °C to just below Tc while the screen oscillates at different frequencies and amplitudes.

Previous Results

CVX operated well on its first flight on STS–85 in 1997. It accurately measured the viscosity of xenon to within 0.0001 °C of Tc and showed a viscosity increase of 37 percent, double the best measurements on Earth. CVX also showed that xenon's viscoelastic response (a partly elastic response to shear stress) was twice as great as predicted by theory. The results have been published in *Physical Review Letters* (**82**: 920-923, Feb. 1, 1999).

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